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The complexity of technological capital and legal protection mechanisms

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Abstract

Purpose – The purpose of this paper is to analyze the effectiveness of legal protection mechanisms to sustain competitive advantage and appropriate technological intellectual capital, taking into account its degree of complexity.

Design/methodology/approach – The empirical analysis was conducted on a sample of Spanish biotechnology firms, devoted to human and animal health, having a specific department for carrying on R&D activities from 2001 to 2003. The hypotheses were tested by non-parametric techniques after collecting data by sending a questionnaire as the primary source of information.

Findings – The results show that the higher the complexity of technological knowledge, the greater the protection of intellectual capital against imitation. In addition, it is proven that legal protection is an effective means of protection against imitation only when technological knowledge has a low degree of complexity.

Research limitations/implications – Within the resource-based view context, our results provide new empirical evidence about the great impact of the complexity of technological intellectual capital on evaluating the effectiveness of legal protection mechanisms and sustaining competitive advantage.

Originality/value – This research is of great value for strategic technological decision-making. Although several studies present the theoretical conditions that explain how firms can create imitation "barriers", the empirical evidence found is very scarce and controversial, especially for the Spanish biotechnology industry. The results obtained here offer new empirical evidence on the resource-based view.

Keywords Intellectual capital, Complexity theory, Economic sustainability, Competitive advantage

Paper type Research paper

1. Introduction

In the current economic environment, developing and exploiting the intellectual capital formed by technological capabilities is seen as one of the basic foundations upon which firms should base their competitiveness, especially in dynamic and knowledge-intensive industries (Afuah, 2002; DeCarolis, 2003; Nicholls-Nixon and Woo, 2003; Zott, 2003; Wang *et al.*, 2004). In fact, one of the issues addressed by the strategic management literature has been the analysis of the features of intangible assets that determine the creation and maintenance of competitive advantage, and subsequently appropriating rents, derived from such firm capabilities (Helfat, 2000; Makadok, 2003; Lippman and Rumelt, 2003; Peteraf and Bergen, 2003).

The resource-based approach and its subsequent developments – the dynamic capabilities approach (Teece *et al.*, 1997; Bowman and Ambrosini, 2003) or knowledge-based theory (Nonaka and Takeuchi, 1995; Grant, 1996; Mohrman *et al.*, 2003; Spender, 1996; Styhre, 2004; Un and Cuervo-Cazurra, 2004) – have mainly focused on analyzing the criteria that must be fulfilled for resources and capabilities to

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be a source of sustainable competitive advantage. A study of the previous literature shows that there are almost as many proposals of business asset evaluation criteria as studies based on their analysis. Nevertheless, the variety of terminology and overlap of proposals hinders comparison of such studies and development of the strategy discipline (Peteraf, 1993; Black and Boal, 1994).

From our point of view, rather than the mere theoretical description of criteria dealing with the strategic value of knowledge, the most important issue rests on those variables explaining the fulfillment of such criteria. Precisely, the purpose of this research is focused on studying the role of legal protection mechanisms in sustaining competitive advantage, taking into account the possible contingent effect of the more or less complex nature of the technological knowledge to be legally protected.

From an organizational point of view, our analysis is justified because many different effects of knowledge complexity are still understudied (Kim and Wilemon, 2003; Mote, 2005), like its influence on operations productivity or its effects on either system renewal or external agents' possibilities to understand how leader competitors' capabilities work. This last question will centre our attention on the specific case of technological intellectual capital, since previous empirical models relating knowledge complexity to maintaining competitive advantage do not provide conclusive results at all (McEvily *et al.*, 2000; Spencer, 2003).

Furthermore, although some researchers either argue theoretically (Griliches, 1990; Ernst, 1995; Liebeskind, 1996, 1997) or demonstrate empirically (Scherer, 1965; Comanor and Scherer, 1969) that the legal protection of knowledge is one of a firm's most important instruments in taking full advantage of the results of its research[1], other authors support contrasting arguments. Empirical results increasingly show that the constant effort to legally protect knowledge may, in fact, be greater than the potential benefits from doing so (Rivette and Kline, 2000; DeCarolis, 2003; Spencer, 2003). The complete analysis of these variables is oriented to better understanding all these relationships.

Besides the sign and intensity of the relationship between variables, the results obtained here offer new empirical evidence on the resource-based view. In addition, they enable us to acknowledge the existence of a substitution effect between both knowledge protection alternatives – legal and complexity-based ones. Therefore, although different studies have defended legal protection systems as being highly efficient alternatives in all cases, our study shows evidence that challenges their use under high complexity conditions.

The paper is structured as follows. First, the theoretical framework is developed. Second, the model and the hypotheses to be tested are defined. Third, the most important empirical features are addressed, and, finally, results and most relevant conclusions, as well as possible areas of future research, are presented.

2. Theoretical foundations and model of analysis

2.1 The concept of technological intellectual capital

A large number of terms exist to refer to the intangible elements used by firms to carry out their activities, like intellectual capital, resource, skill, capability, know-how, competence, asset or factor. Each one of them has special features that distinguish it from the rest; however, not all studies link the same properties to the same concept,

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therefore substantially increasing the difficulty of constructing a solid theoretical framework and contrasting empirical hypotheses (DeCarolis, 2003).

In this study we will focus on that kind of intellectual capital related to technological knowledge, the one directly linked to those firm capabilities that jointly mobilize different scientific and technical resources accumulated by a series of routines and procedures, thus enabling a firm to develop its innovative products and/or productive processes (Prahalad and Hamel, 1990; Grant, 1991; Black and Boal, 1994; Christensen, 1996; Miller and Shamsie, 1996; Wiklund and Shepherd, 2003; Fowler *et al.*, 2000).

Finally, we would like to remark that our research is defined from a technological output point of view, as we did not focus on accumulating and developing knowledge, but on those variables that, to some extent, explain the strategic value of technological assets by the sustainable character of the competitive advantages they promote.

2.2 Theoretical analysis of technological knowledge complexity

Complexity of systems can be defined in a wide sense as the difficulty of degree in understanding how their components work to transform some inputs into successful results (Wonglimpiyarat, 2005). From an organizational point of view, our analysis is justified because many different effects of complexity are still under-studied (Kim and Wilemon, 2003; Mote, 2005), like its influence on operations productivity or its effects on either system renewal or external agents' possibilities to understand how leader competitors' systems function.

If we apply this concept to technological intellectual capital, complexity can be defined as the difficulty in identifying the pieces of knowledge that constitute it, and understanding how they work together. Then, we can state that this variable is a basic feature of the embedded elements of knowledge relating to the determining of its strategic value, as notably affects a competitor's ability to imitate it (Lippman and Rumelt, 1982; Reed and DeFillippi, 1990; Barney, 1992; Black and Boal, 1994; Miller and Shamsie, 1996; Vicente-Lorente, 2001; Wilcox-King and Zeithaml, 2001). However, as we have commented above, the empirical models relating knowledge complexity to success do not provide conclusive results at all; an insufficient study of the concept of complexity could explain this situation.

Simon (1962) considered a system to be complex when it was made up of numerous specific inter-related elements that have similar effects on the output of the system. From our point of view, Simon's definition is too restrictive, as it requires all pieces of knowledge to be individual, tacit and specific for a system to be complex.

Alternatively, Singh (1997) and Deeds (2001) consider that a complex technology is the result of systems comprised of different components with multiple interactions and unable to be decomposed[2]. Similarly, Mote (2005, p. 95), following Larson and Gobeli's (1989) approach, defined scientific complexity as "the number of disciplines and departments involved in a R&D project". Novak and Eppinger (2001) describe complexity or architecture of systems as a function of the number of components and the extent of interactions between these components. Furthermore, Novak and Eppinger (2001) include an additional complexity element dealing with the system degree of novelty. In a similar sense, Deeds (2001) considers that technological capabilities are more or less complex systems taking into account the number of key components integrated within them.

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From these last definitions, we can conclude that technological intellectual capital does not necessarily have to fulfill Simon's condition to be complex, related to tacit and specific knowledge. In this sense, it is possible that the particular use of explicit public technological knowledge, in the complementary presence of other intangible elements, may be difficult to identify and understand (Adler and Shenhar, 1990; Black and Boal, 1994; Miller and Shamsie, 1996; Thomke and Kuemmerle, 2002). The incorporating of general use knowledge to a specific organization may result in the firm developing processes that competitors are not able to copy or even identify.

The root of these arguments lies in the phenomenon known as asset inter-dependence or co-specialization, put forth by Teece (1986) some years ago. Similarly, Robins (1992) suggests a theoretical model supported by these arguments and acknowledges that firms may have access to specific and exclusive assets (X-assets) that they use in their business processes, together with others that are available on the market. All these aspects will be taken into account when defining and measuring the complexity construct.

2.3 Sustaining a technology-based competitive advantage: imitability of technological intellectual capital

Effectively sustaining a technology-based competitive advantage can be defined as maintenance of a privileged position as leader, once other agents have given up in their attempts to reach it (Hirshleifer, 1982; Lippman and Rumelt, 1982). Numerous criteria have been put forth to evaluate the sustainability of competitive advantage; however, this study has opted for one criterion that, in our opinion, simply and comprehensively covers the phenomenon we wish to analyze – *imitability*.

The imitability of a particular knowledge can be understood as how easy is for competitors to copy it using their own means. Since it was acknowledged that imperfect imitability was one of the main features a capability had to possess in order to be strategic (Dierickx and Cool, 1989; Reed and DeFillippi, 1990; Barney, 1991; Amit and Schoemaker, 1993; Fernández Sánchez *et al.*, 1999), the study of "barriers" to the imitation of assets has been substantial, although the results are not at all conclusive. These imitation "barriers" can be broadly defined as all legal or natural impediments that make copying or reproduction processes more difficult for other agents.

2.4 Model of analysis: hypotheses

According to the references above, special mention should be made to the fact that, in addition to acknowledging imperfect imitability as essential criterion for strategically evaluating technological knowledge, the real interest rests on the analysis of the factors that increase imitation "barriers". To contribute to better understand this fact we develop the present model of analysis.

First, although several studies present the theoretical conditions that explain the creation of imitation "barriers", the empirical evidence found in relation to their effects on value creation is controversial. Although on certain occasions the sustaining of a competitive advantage has been linked to legal protection systems (Scherer, 1965; Griliches *et al.*, 1991; Ernst, 2001), it is related to the nature of the underlying organizational knowledge too (McGrath *et al.*, 1995; Wilcox-King and Zeithaml, 2001; Fuentelsaz *et al.*, 2003; McEvily and Chakravarthy, 2002).

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The complex, tacit and specific nature of knowledge are features that have been attributed the greatest influence on sustaining certain favorable competitive advantages. Traditionally, literature has acknowledged their beneficial effects, given that they appear to provide imitation "barriers", by making it more difficult to identify pieces of knowledge and their contribution to innovative results (Lippman and Rumelt, 1982; Dierickx and Cool, 1989; Reed and DeFillippi, 1990; Barney, 1992; Amit and Schoemaker, 1993).

For the specific case of technological assets, empirical models exist to support these theoretical approaches. In this respect, MacMillan *et al.* (1985) or Rogers (1995) state that new technologies are adopted more quickly by competitors when the uncertainty of their strategic implications is limited.

The literature has traditionally recognized the beneficial effects of the tacit nature of intangibles, resulting from its role in building "barriers" to imitation (Lippman and Rumelt, 1982; Dierickx and Cool, 1989; Reed and DeFillippi, 1990; Barney, 1992; Amit and Schoemaker, 1993). Several empirical studies have concluded that this type of knowledge has a positive effect on its imperfect imitability, when developed by a firm's own resources (MacMillan *et al.*, 1985; Rogers, 1995; Afuah, 2002; Figueiredo, 2002; McEvily and Chakravarthy, 2002; Miller *et al.*, 2002; Zahra and Nielsen, 2002; Nicholls-Nixon and Woo, 2003). Taking into account the basic premise that imperfect imitation is directly related to the difficulty in identifying the elements that make up technological capital and understanding how it works, our first hypothesis can be defined as follows:

H1. The complexity of technological knowledge is positively related to its imperfect imitability.

From this perspective, in spite of the arguments put forth by several studies, it is possible to question the real interests to legally protect complex technological knowledge, as such complexity may act as a natural protection barrier.

Some researchers theoretically argue that the legal protection of knowledge is one of a firm's most important instruments in taking full advantage of the results of its research. The benefits of legal protection practices are considered to justify their costs in almost all situations (Griliches, 1990; Ernst, 1995; Liebeskind, 1996, 1997). In this sense, certain pioneer empirical models find evidence to support the expected effect (Scherer, 1965; Comanor and Scherer, 1969)[1].

However, in other cases, theoretical arguments are contrary to the mentioned above, and empirical results increasingly show that the constant effort to legally protect knowledge may, in fact, be greater than their potential benefits (DeCarolis, 2003; Spencer, 2003). In other words, the costs that a firm has to incur, both in the concession and maintaining of intellectual property within a particular geographical area as well as the conflict with other firms that commit offences under the Intellectual Property Act, are excessive (Rivette and Kline, 2000).

According to these alternative approaches, we propose the following hypothesis, which, in addition, enables us to observe a possible substitution effect between complexity and legal protection practices, in relation to sustained competitive advantage based on the degree of imitability:

H2. Legal protection of technological knowledge is positively related to its imperfect imitability.

Figure 1 presents graphically the model used to analyze the proposed hypotheses.

Finally, we would like to remark that these relationships may be moderated by some external variables. In this sense, some expressions of complex knowledge could be of great interest for competitors if, for example, they consider them as strategic factors for firm success; then, these technological capabilities may be more vulnerable to imitation by competitors. To take into account these external influences, we study one specific industry and include some additional control variables dealing with factors than can notably influence sustaining competitive advantages, like the market value of technology or its novelty degree. Analyzing the influence of these variables, we will estimate the global effect of complexity and legal mechanisms on sustaining competitive advantage, regardless of competitors' propensity to imitate technological knowledge.

3. Methodology: sample, data analysis and measures

Once we have defined the concept of complexity and the model of analysis, we take on the empirical study. Following the arguments proposed by several authors, we established a homogeneous population of knowledge-intensive firms (Hoskisson *et al.*, 1999; Yeoh and Roth, 1999; DeCarolis, 2003; Douglas and Ryman, 2003; Rothaermel and Deeds, 2004). Therefore, the firms studied are facing the same external conditions as well as similar levels of technological and market opportunity.

The empirical analysis was conducted on 52 firms devoted to human and animal health using biotechnological processes and having a specific department for developing R&D activities. Finally, 34 companies decided to participate.

The biotechnological industry is one of the most important emerging sectors due to the numerous possible applications that this technology has, many of which are yet to be explored. One of the main problems in identifying the biotechnology sector is that it still lacks its own identity, due to its extremely horizontal nature (ASEBIO, 2000). In addition, the practical absence of updated nationwide statistics on firms that carry out activities in Spain made it necessary to prepare a company census using the database created in 1997 by the Scientific Information and Documentation Center (CINDOC)[3].

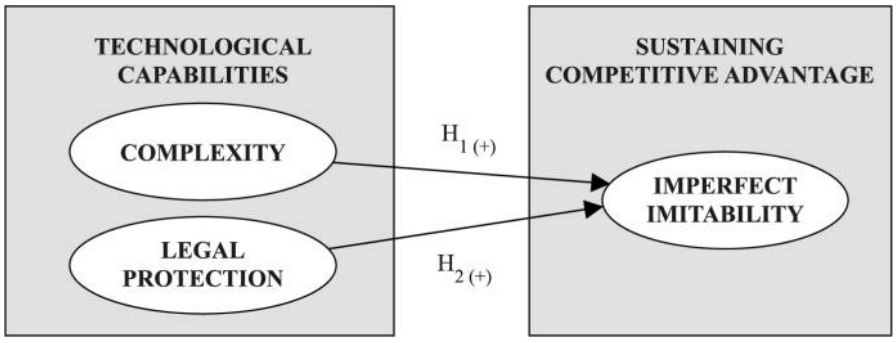

Figure 1.
Model of analysis

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The desired uniformity of firms meant that several criteria had to be fulfilled, especially in relation to the firm belonging to certain segment of activity within the biotechnology industry; therefore, the firms analyzed were those involved in either human or animal health. The widespread social disapproval of biotechnology activities in the food and environmental sectors, recognized by almost all experts interviewed, as well as Orsenigo's (2001) comment supporting the same idea, made us aware that analyzing the companies involved would be much more difficult.

The activities of the firms we included refer to biotechnology products and services that focus on a limited number of therapeutic areas, being involved in the treatment, prevention and diagnosis of diseases (production of vaccines, antibiotics, medicines, diagnostic kits, xeno-transplants, genomic medicines or cellular engineering). Following suggestions made by industry experts, only small Spanish firms (up to 50 employees) developing biotechnological engineering were included, as bigger companies working on it are usually multinational pharmaceutical groups making only technological efforts partially in Spain; in addition to this, their inclusion would alter the unit of analysis. Furthermore, this kind of organization constitutes a minimal proportion of the entire population.

The main method features are summarized in Table I.

The study included developing two main phases: during the first phase, opinions and suggestions from managers and industry experts were used to identify:

- some key industry success factors;
- suitable measures for the included variables; and
- some key issues dealing with biotechnological innovations.

During the second phase, the accumulated information was employed to define a preliminary version of the questionnaire, which was sent to managers after being pre-tested and redefined.

The nature of the sample chosen for our study substantially fulfils the profile for the statistical data analysis process. The limited size of the firms chosen, and thus of the sample itself, made it advisable to use non-parametric statistics (Siegel and Castellan, 1988), as there is no guarantee that the complete model would behave like a normal multi-variant variable. Besides, according to observations, the number of variables

Population	Spanish biotech companies up to 50 employees
Total population	52 firms
Sample	34 firms
Participation	65 percent
Confidence level	95 per cent ($z = 1.96$)
Sample error	± 8.32 percent (for the worst case, where $p = q = 0.5$)
Sample procedure	Questionnaire was sent to every firm in the population
Geographical area	Spain
Period of analysis	2001-2003
Level of analysis	Firm
Period of execution	February-September 2004
Sources of information	Primary: questionnaire sent via electronic devices to the R&D manager or CEO

Table I.
Empirical research technical data

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included in the model makes it less advisable to use statistical parametric methods, due to the resulting degrees of freedom. Non-parametric models are based on the assumption that the data does not follow a particular distribution and, therefore, do not have parameters to measure them. The data available and hypotheses defined suggested that they should be contrasted by the Mann-Whitney U test, also known as the Wilcoxon W test, using the SPSS set of statistics.

Both tests state if two independent samples are extracted from the same population. To do that, they verify if observations from one sample differ substantially to those included in the other sample. To implement the test it was necessary to classify firms in two groups taking into account their relative position to the median of the dependent variable (i.e. maintenance of competitive advantage). These were the X group, constituted by those firms with non-vulnerable technological knowledge, and the Y group, formed by those firms with more vulnerable technological knowledge. We chose the median value as we consider it reflects more appropriately the firm relative position to the rest of competitors. Furthermore, the shortcomings of using the mean value when deviation is high are avoided too.

Once firms were classified, we tested whether both groups of companies differed in the character knowledge embedded in their respective technological capitals and their propensity to protect such knowledge legally.

Data used for the dependent variable were collected for three years (2001-2003), and the value used to test hypotheses was the mean for the entire period of analysis. With respect to the independent variable, we asked managers to estimate the complexity of the accumulated capabilities by which firms developed successful innovations from 2001 to 2003. To some extent, the empirical evidence obtained can be interpreted from a process approach, since the independent variable reflects the characterization of previously developed capabilities.

The next section is devoted to defining measures[4].

3.1 Measuring technological capital complexity

One of the key issues of this research was focusing on defining and measuring the capability complexity construct. Creating a new measure of complexity from a multidimensional approach was our first empirical research objective. Following different surveys proposed by several authors (Wilcox-King and Zeithaml, 2001; McEvily and Chakravarthy, 2002), we defined a preliminary version of a seven-point Likert multi-item scale to measure complexity.

The first step was the development of a reliability analysis for the complete scale. According to the results obtained, an insufficient level of reliability can be observed ($\alpha = 0.6032$). Somehow, this fact can reflect the lack of an internal consistency among items and the existence of various underlying complexity dimensions. After that, the next step was developing an exploratory factorial analysis. Table II shows the main results in order to check the suitable character of data.

As we show in Table III, two different dimensions can be identified within technological complexity where. The first element or factor (F_1) includes items related to those aspects regarding to the complementary use of explicit expressions of knowledge (V_3, V_4, V_5, and V_6).

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The second factor (F_2) refers to the tacit knowledge exclusively. In this sense, items included in this second element are related to the degree of difficulty to transfer and observe the strategic tacit technological knowledge (V_1 and V_2), based on previous direct experiences (V_7), and somehow difficult to codify (V_8).

Additionally, on the one hand, we observe that with respect to the complete scale, the reliability of the two subscales has been improved notably. On the other hand, the analysis of the bivariate correlation matrix (see Table IV) among items let us notice the fulfillment of the concept/construct validity according to the convergent approach, as just only those variables included in the same factor are highly correlated.

Although in this study we will consider complexity without taking into account its qualitative composition, future research will be oriented to the specific effects of each dimension on sustaining competitive advantage.

3.2 Measuring legal protection mechanisms

In the literature, different quantitative approaches to measure legal protection instruments have been defined (Scherer, 1965; Levin *et al.*, 1987; Miller and Shamsie, 1996; Ernst, 2001; Miller *et al.*, 2002; Spencer, 2003). In these cases the proposed measures refer to the number of patents and/or confidentiality agreements. Other alternative indicators include the quality of protected knowledge evaluating its international character or the number of references found in subsequent patents (Yeoh and Roth, 1999; Fleming, 2001; Jaffe and Lerner, 2001; Mangematin *et al.*, 2003). In our survey we included standard measures: the number of patents and confidentiality agreements/total of innovations for the period of analysis[5].

3.3 Measuring the maintenance of competitive advantage

As we pointed out previously, in this paper we have defined sustaining of competitive advantages in terms of "barriers" to imitation. In this case, we proposed quantitative measures for this variable. Following Figueiredo (2002) and McEvily and Chakravarthy's (2002) works, we measured the sustaining of competitive advantage as the time spent by competitors copying technological innovations in relation to the time such innovations are useful for customers.

In addition, we included two control variables dealing with factors that can notably influence sustaining competitive advantage:

(1) the degree of technology novelty; and

(2) the market value of technology.

The first refers to the time leader firms have been working with the technology. Similarly to Novak and Eppinger's (2001) arguments, more recent technologies will probably be more difficult to understand and then copy by competitors. The second

Table II. KMO and Bartlett's test for technology complexity construct

Maiser-Meyer-Olkin		0.807
Bartlett's test	χ^2	77.105
	FD	36
	Sig.	0.000

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Items	Initial auto-value Total	Percentage of variance explained	Cumulative percentage	Sum of extraction squared saturation Total	Percentage of variance explained	Cumulative percentage	Sum of rotation squared saturation Total	Percentage of variance explained	Cumulative percentage
Item 1	3.474	43.422	43.422	3.474	43.422	43.422	3.161	39.517	39.517
Item 2	1.644	30.549	73.971	1.644	30.549	73.971	1.956	34.454	73.971
Item 3	0.964	12.054	76.025						
Item 4	0..595	7.434	83.459						
Item 5	0.555	6.941	90.400						
Item 6	0.336	4.206	94.606						
Item 7	0.252	3.145	97.751						
Item 8	0.180	2.249	100.000						

		Component λ_{i1}	λ_{i2}
Rotated components matrix [a]			
$Item_5$; V_5	Worker coordination	*0.870*	0.023
$Item_4$; V_4	Department coordination	*0.854*	0.036
$Item_3$; V_3	Number of technologies, concepts, parameters and factors	*0.816*	0.091
$Item_6$; V_6	Technology complementarity	*0.779*	0.186
$Item_2$; V_2	Knowledge transference difficulty degree	0.373	*0.785*
$Item_1$; V_1	Knowledge observation	0.399	*0.748*
$Item_7$; V_7	Accumulated experience by workers	−0.022	*0.706*
$Item_8$; V_8	Knowledge codification	0.321	*− 0.488*
Reliability of subscales		$\alpha_1 = 0.8478$	$\alpha_2 = 0.7503$
		F_1	F_2

Notes: Extraction method: principal component analysis. Rotation method: Varimax with Kaiser normalization. [a]Rotation converged in three iterations

Table III.
Exploratory factorial analysis results

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Table IV.
Complexity of technological capabilities: correlation matrix

			Correlation matrix							
Kendall tau_b	Knowledge observation	Correlation coefficient	1.000							
		Sig. (bilateral)	–							
	Knowledge transference difficulty degree	Correlation coefficient	*0.569* **	1.000						
		Sig. (bilateral)	0.000	–						
	Number of technologies, concepts, parameters, factors	Correlation coefficient	0.304	0.298	1.000					
		Sig. (bilateral)	0.058	0.062	–					
	Department coordination	Correlation coefficient	0.277	0.288	*0.500* **	1.000				
		Sig. (bilateral)	0.093	0.081	0.003	–				
	Worker coordination	Correlation coefficient	0.295	0.310	*0.436* *	*0.732* **	1.000			
		Sig. (bilateral)	0.077	0.062	0.010	0.000	–			
	Technology complementarity	Correlation coefficient	0.187	−0.066	*0.484* **	*0.525* **	*0.608* **	1.000		
		Sig. (bilateral)	0.252	0.677	0.004	0.002	0.000	–		
	Accumulated experience by workers	Correlation coefficient	*0.324* *	*0.333* *	0.054	0.118	0.061	0.116	1.000	
		Sig. (bilateral)	0.043	0.037	0.741	0.482	0.720	0.485	–	
	Knowledge codification difficulty degree	Correlation coefficient	− *0.349* *	−0.066	0.228	0.217	0.141	−0.036	−0.023	1.000
		Sig. (bilateral)	0.032	0.678	0.159	0.193	0.401	0.829	0.888	–

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variable tries to control the fact that more value technologies could be the ones in which competitors may be more interested in imitating.

4. Results

Our first comment is related to control variables. As we used non-parametric tests, we had to develop an individual analysis dealing with such variables. The results indicated that, for the sample studied, the degree of technology novelty and the market value of technology did not have significant effects on sustaining competitive advantages. The homogeneous character of the population analyzed may be one reason for such results. Thus, we can conclude that the effects of complexity and legal protection mechanisms on maintaining competitive advantage are not substantially altered by technology novelty and market value of technological knowledge.

In addition to the previous classification of firms into groups X and Y, we developed a descriptive analysis to characterize the firms' technological capital in terms of their complexity, distinguishing firms with complex technological intellectual capitals from those with more transparent ones[6].

The first hypothesis suggested the existence of a positive relationship between complexity and "barriers" to imitation. The empirical analysis tested if knowledge imitability was greater in firms with simple or *transparent* knowledge than in the remaining organizations.

As can be observed in the table of ranks in Table V, firms with knowledge that are less likely to be imitated show higher levels of overall complexity ($12.41 > 8.44$); this relationship is significant at a level of 10 percent, according to an analysis of the significance of the statistic Z_1; therefore, the higher the degree of a knowledge's complexity, the greater the natural protection against imitation by competitors.

	Imitability	*n*	Mean rank	Sum of ranks
Complexity	Low	20	12.41	248.20
	High	14	8.44	118.16
	Total of firms	34		
Legal protection	Low	7	13.00	91.00
	High	5	7.44	37.20
	Total of firms with complex capabilities	12		

	Complexity	Legal protection
Statistics [a]		
Mann-Whitney *U*	39.500	22.000
Wilcoxon *W*	11.160	37.200
Z	Z_1: -1.746^{*}	Z_2: -2.159^{**}
Sig. (bilateral	0.082	0.031

Notes: [a]Grouping variable: imitability; $^{*}p < 0.10$; $^{**}p < 0.05$; $^{***}p < 0.01$

Table V.
Knowledge complexity, legal protection, and imitability

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These results are coherent with widespread theories in literature, as well as with the several empirical studies that directly link tacit knowledge to certain measures of technological success (e.g. Afuah, 2002; Balconi, 2002; Figueiredo, 2002; McEvily and Chakravarthy, 2002; Miller *et al.*, 2002; Zahra and Nielsen, 2002; Nicholls-Nixon and Woo, 2003).

With respect to legal protection mechanisms, the results for *H2* concluded no existence of a significant relationship between them and imitability for the entire sample. Nevertheless, it was possible that the complexity of the knowledge makes its protection by additional legal "barriers" unnecessary. Therefore, we analyzed the effect of legal systems on imitability for firms having more transparent or simple knowledge only. In this case the results showed that legal systems were useful to build "barriers" to imitation ($13.00 > 7.44$). These results allow us to conclude the existence of a substitution effect between legal and natural systems to prevent technological knowledge from imitation. *H1* can therefore be accepted, whereas *H2* can only be accepted in the case of non-complex technological knowledge.

5. Discussion, limitations, and future research

This research, in addition to theoretically advancing the study of different concepts and variables, is of great value for strategic technological decision-making. Within the resource-based view context, our results provide new empirical evidence supporting that the complexity of technological intellectual capital has a great impact on evaluating the effectiveness of legal protection mechanisms and sustaining competitive advantage. Also, there is some empirical evidence to answer "yes" to the following question: does the complexity of technological intellectual capital challenge the effectiveness of legal protection mechanisms?

Results for the relationship between complexity and "barriers" to imitation are in line with previous and current research that highlights the strategic role of tacit and specific knowledge in wealth creation (Afuah, 2002; Balconi, 2002; Figueiredo, 2002; McEvily and Chakravarthy, 2002; Miller *et al.*, 2002; Zahra and Nielsen, 2002; Nicholls-Nixon and Woo, 2003).

In addition, we found that legal protection is only an efficient mechanism against imitation when technological knowledge is not complex; otherwise, the efforts made are not converted into greater protection against such imitation, as was supported by the most recent literature dealing with the issue (Rivette and Kline, 2000; DeCarolis, 2003; Spencer, 2003). Nevertheless, the existence of an internal structure within the complexity construct may open several new issues in the relationship between complexity of assets and firm value creation to be addressed in future research.

While our results provide statistical support for our hypotheses, we must also acknowledge several limitations to be overcome in future research. Our focus on the biotechnology industry raises questions about the generalizability of our study beyond this industry. Defining a wider population of firms would have allowed us to use regression equations, where both independent and control variables could have been included simultaneously, enriching our results and conclusions notably.

Although we defined variables and measures in such a way to design a process model, we have to recognize the prominent cross-sectional nature of the research.

Furthermore, since we only included the relationship between complexity and sustaining competitive advantage, in future studies other complementary issues regarding value creation process could be analyzed, like gaining competitive advantage, rent appropriation or maintaining competitive advantage by other alternative processes such as barriers to substitution or continuous improvement.

Our next research project will be designed to overcome these shortcomings and contrast new relationships in order to complete a model that integrates the main factors responsible for technological and entrepreneurial success in a specific environment.

Notes

1. In any case, it must be pointed out that the positive effects on corporate success are more significant when accounting rather than economic measures are used; it can even be observed that the sign of the relationship changes when an organization's success is measured by one or the other (DeCarolis, 2003).
2. These authors take as basic references the previous works of Huberman and Hogg (1986), Anderson *et al.* (1988) and Holland and Miller (1991).
3. Spanish Research Groups and Enterprises Working in Biotechnology.
4. In the Appendix we include the questionnaire dealing with the variables used for the present study.
5. Although we included some indicators related to quality of knowledge, the age of the firms studied makes them unsuitable.
6. The classification of each observation in one or another group was determined by the firm's position in relation to the distribution's median of complexity variable. In contrasting *H1*, all firms whose capabilities had high levels of complexity were included in the high total complexity group, and the remaining ones were included in the low total complexity group (group D).

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Appendix

1. Complete the next table related to firm **technological innovation results**:

	2001	2002	2003
Number of incremental technological innovations			
Number of radical technological innovations			
Number of patents and confidentiality agreements signed			
	TECHNOLOGICAL INNOVATIONS		
Mean time to develop technological innovations (months)			
Mean time technological innovations are accepted by customers (months)			
Mean time until imitations appeared (months)			
Mean time until substitutes appeared (months)			

Number of times your patents have been referred in subsequent ones:
Percentage of patents that have internationally been approved:

2. Point out your **degree of agreement** with respect to the following sentences related to nature of technological knowledge:

Statements	*Total disagreement*						*Total agreement*
Identification of technological knowledge related to successful innovations its difficult for competitors	1	2	3	4	5	6	7
Technological knowledge is difficult to understand, transfer and exploit by external agents who were not involved in its creation and development	1	2	3	4	5	6	7
The number of technologies, concepts, factors, and parameters relevant for innovation is high	1	2	3	4	5	6	7
Technological innovations demand a strong coordination and sharing knowledge between different departments	1	2	3	4	5	6	7
It is difficult that one employee has all the necessary knowledge to develop one specific technological innovation	1	2	3	4	5	6	7
Success of innovations notably depends on the complementary control of several technologies	1	2	3	4	5	6	7
Relevant employees for developing technological innovations have a great experience in the biotechnological industry	1	2	3	4	5	6	7
Relevant employees for developing technological innovations have a great experience in the firm	1	2	3	4	5	6	7
The cognitive facts in which technological innovations are based on can be expressed in words	1	2	3	4	5	6	7
My company dominate the base of technological knowledge for a long time	1	2	3	4	5	6	7
Using external technologies are improved by the internal base of firm-specific technological knowledge	1	2	3	4	5	6	7

Figure A1.
Part of the questionnaire sent to biotech firms dealing with complexity, legal protection mechanism and maintenance of competitive advantage

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